# INDOOR AIR QUALITY ASSESSMENT

**Priest Street School**
**Modular Classroom Building**
**115 Priest Street**
**Leominster, Massachusetts**


Prepared by:
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Center for Environmental Health
Bureau of Environmental Health Assessment
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## Background/Introduction

At the request of Christopher Knuth, Director, Leominster Board of Health, the Massachusetts Department of Public Health (MDPH), Center for Environmental Health's (CEH) Bureau of Environmental Health Assessment (BEHA) conducted an assessment of the indoor air quality at the Priest Street School (the school), 115 Priest Street, Leominster, Massachusetts. Concerns about mold growth and other indoor air quality conditions in the modular classroom structure prompted the request.

On June 11, 2004, Michael Feeney, Director, Emergency Response/Indoor Air Quality (ER/IAQ), BEHA, visited the school to conduct an indoor air quality assessment. Mr. Feeney was accompanied by David Wood, Director of Facilities, Leominster Public Schools and for portions of the assessment, Mr. Knuth.

The main school building is a brick and wood structure built in 1894. Wings were added to the building in 1918. The modular building is a freestanding structure that was erected at the rear of the main building in 1994. The modular structure contains two classrooms, two restrooms and a utility room. The modular classrooms are the subject of this report. The indoor air quality assessment of the main building is the subject of a separate report. Windows in the modular building are openable.

## Methods

BEHA staff performed visual inspection of building materials for water damage and/or microbial growth. Air tests for carbon monoxide, carbon dioxide, temperature and relative humidity were conducted with the TSI, Q-Trak, IAQ Monitor, Model 8551. Air tests for airborne particulate matter with a diameter less than 2.5 micrometers were taken with the TSI, DUSTTRAK™ Aerosol Monitor Model 8520. Screening for total volatile organic compounds was conducted using a Thermo Environmental Instruments Inc., Model 580 Series Photo Ionization Detector (PID).

## Results

The school houses approximately 290 students in kindergarten through first grade and a staff of approximately 35. The tests were taken during normal operations at the school. Test results appear in Table 1.

## Discussion

### Ventilation

It can be seen from Table 1 that carbon dioxide levels were below 800 parts per million (ppm) in both classrooms; however, one classroom was empty during the assessment. Carbon dioxide levels would be expected to increase when a room is fully occupied.

Ventilation in the modular classrooms is provided by two rooftop air handling units (AHUs) (Picture 1), which were deactivated at the time of the assessment. A thermostat controls the heating, ventilating and air conditioning (HVAC) system. Thermostats have settings of "on" and "automatic". Thermostats were set to the "automatic" setting. The automatic setting on the thermostat activates the HVAC system at a preset temperature. Once a preset temperature is measured by the thermostat, the HVAC system is deactivated. Therefore no mechanical ventilation is provided until the thermostat re-activates the system.

The fresh air intakes for the AHUs were sealed with sheet metal (Picture 2), thereby limiting the ability to provide fresh air. Since the AHUs do not have the ability to exhaust air, the operation of the AHUs would be expected to recirculate air. Modular classrooms are designed to be energy efficient; therefore, little outside air penetration occurs, except when windows are open. Under these conditions, concentrations of normally occurring environmental pollutants (e.g., heat, odors) can build up, resulting in increased comfort complaints for some individuals.

To maximize air exchange, the BEHA recommends that both supply and exhaust ventilation operate continuously during periods of school occupancy. In order to have proper ventilation with a mechanical supply and exhaust system, these systems must be balanced to provide an adequate amount of fresh air to the interior of a room while removing stale air from the room. It is recommended that HVAC systems be re-balanced every five years (SMACNA, 1994). In its current condition (e.g., lack of supply and exhaust ventilation), the mechanical ventilation system cannot be balanced.

The Massachusetts Building Code requires that each room have a minimum ventilation rate of 15 cubic feet per minute (cfm) per occupant of fresh outside air or openable windows (SBBRS, 1997, BOCA, 1993). The ventilation must be on at all times that the room is occupied. Providing adequate fresh air ventilation with open windows and maintaining the temperature in the comfort range during the cold weather season is impractical. Mechanical ventilation is usually required to provide adequate fresh air ventilation.

Carbon dioxide is not a problem in and of itself. It is used as an indicator of the adequacy of the fresh air ventilation. As carbon dioxide levels rise, it indicates that the ventilating system is malfunctioning or the design occupancy of the room is being exceeded. When this happens a buildup of common indoor air pollutants can occur, leading to discomfort or health complaints. The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 parts per million parts of air (ppm). Workers may be exposed to this level for 40 hours/week based on a time weighted average (OSHA, 1997).

The Department of Public Health uses a guideline of 800 ppm for publicly occupied buildings. A guideline of 600 ppm or less is preferred in schools due to the fact that the majority of occupants are young and considered to be a more sensitive population in the evaluation of environmental health status. Inadequate ventilation and/or elevated temperatures are major causes of complaints such as respiratory, eye, nose and throat irritation, lethargy and headaches. For more information concerning carbon dioxide, please see Appendix A.

Temperature readings ranged from 72° F to 74° F, which were within the BEHA recommended range. The BEHA recommends that indoor air temperatures be maintained in a range of 70 ° F to 78 ° F in order to provide for the comfort of building occupants. In many cases concerning indoor air quality, fluctuations of temperature in occupied spaces are typically experienced, even in a building with an adequate fresh air supply. It is also difficult to maintain temperature when fresh air supply vents are sealed.

Relative humidity measurements ranged from 35 to 39 percent, which were close to the lower limit of the BEHA recommended comfort range. The BEHA recommends a range of 40 to 60 percent for indoor air relative humidity. It is important to note that relative humidity measured indoors exceeded outdoor measurements by 5 to 9 percent.

This increase in relative humidity can indicate inadequate exhaust ventilation or that a moisture source is penetrating into the building interior. For example, the restrooms in the modular building are vented. At the time of the assessment, the flexible duct connecting the exhaust fan to the outdoor vent was not attached properly (Picture 3). As a result, water vapor and associated odors from restrooms were venting into the ceiling cavity instead of outdoors, which may be contributing to water vapor accumulation. Additional moisture sources are discussed later in this report.

Moisture removal is important since the sensation of heat conditions increases as relative humidity increases. The relationship between temperature and relative humidity is known as the heat index. As indoor temperatures rise, the addition of more relative humidity will make occupants feel warmer. If moisture is removed, the comfort of the individuals is increased. Removal of moisture from the air, however, can have some negative effects. Relative humidity levels in the building would be expected to drop during the winter months due to heating. The sensation of dryness and irritation is common in a low relative humidity environment. Low relative humidity is a very common problem during the heating season in the northeast part of the United States.

**Microbial/Moisture Concerns**

The Modular Building Institute (Stewart, 2002) released guidance concerning mold growth prevention in modular classrooms in March 2002. According to this guidance, the following improvements can be made to avoid microbial growth within these structures:

1. Ensure structures are constructed with a sloped roof with a properly installed gutter and downspout system to drain rainwater.
2. Site modular structures on well-drained surfaces.
3. Direct surface water run-off away from the structure.
4. Ventilate the crawlspace under the structure.
5. Examine all caulking and/or flashing around windows and service posts, especially after moving a structure.
6. Maintain ventilation according to American Society for Heating, Refrigerating and Air-conditioning Engineers (Stewart, 2002).

BEHA staff examined the modular unit by using the guidelines above as evaluation points. The following conditions concerning water drainage around the structure may have contributed to the increased water vapor noted previously:

- The roof of the modular building does not have a means to drain, due to the rubber membrane roofing material installed over roof drains (Picture 4).
- A significant amount of plant debris is accumulated on the roof (Picture 5).
- The modular building was partially installed on pavement (Picture 6). The rear of the building is installed over soil, onto which downspouts empty. Over time, rainwater has compacted the soil, creating troughs in which water may accumulate against the exterior wall and pool beneath the modular structure.
- The soil at the rear of the modular structure is not graded to slope away from the building. Without grading the soil, rainwater cannot readily drain away from the rear of the structure.

The accumulation of water at the base of the modular building causes chronic wetting of the exterior wall (Pictures 7 and 8). Downspouts should be designed to direct rainwater away from the base of the exterior walls to prevent rainwater from penetrating beneath the building. Wetting of exterior walls and soil beneath the building can result in mold growth.

Of note was a report of mushroom growth on carpeting adjacent to an exterior door. Chronic wetting of the carpet around the door can occur for the following reasons:

- The exterior door is located in the southwestern corner of the building. The prevailing winds in Massachusetts tend to be from the west. Moist weather tends to travel in a northeasterly track, up the Atlantic Coast towards New England (Trewartha, 1943). Wet weather systems generally produce south/southwesterly winds. Driving rain is most likely to strike this door during wet weather patterns.
- A wooden staircase was installed for access beneath this door (Picture 9). The level of the landing stair was installed beneath the door threshold. The door threshold does not have flashing installed to prevent water from penetrating into the doorframe when driving rain runs along the stair landing.
- The door frame threshold was not rendered watertight with the doorframe, providing a water migration pathway.

Splashing rainwater can lead to chronic moistening of the exterior wall and doors, which in turn moistens carpet installed against the doorframe. Mold colonization of the carpet can occur from repeated moistening due to driving rain/melting snow. The American Conference of Governmental Industrial Hygienists (ACGIH) and the US Environmental Protection Agency (US EPA) recommend that porous materials be dried with fans and heating within 24 to 48 hours of becoming wet (ACGIH, 1989; US EPA, 2001). If carpets are not dried within this time frame, mold growth may occur. Water-damaged carpeting cannot be adequately cleaned to remove mold growth. The application of a mildewcide to moldy carpeting is not recommended.

One classroom contained a number of plants. Plant soil, standing water and drip pans can be potential sources of mold growth. Drip pans should be inspected periodically for mold growth and over watering should be avoided.

**Other Concerns**

Indoor air quality can be negatively influenced by the presence of respiratory irritants, such as products of combustion. The process of combustion produces a number of pollutants; however, the pollutant produced is dependent on the material combusted. Common combustion emissions include carbon monoxide, carbon dioxide, water vapor and smoke (fine airborne particle material). Of these materials, exposure to carbon monoxide and particulate matter with a diameter of 2.5 micrometers (μm) or less (PM2.5) can produce immediate, acute health effects upon exposure. To determine whether combustion products were present in the school environment, BEHA staff obtained measurements for carbon monoxide and PM2.5.

Carbon monoxide is a by-product of incomplete combustion of organic matter (e.g., gasoline, wood and tobacco). Exposure to carbon monoxide can produce immediate and acute health affects. According to the NAAQS established by the USEPA, carbon monoxide levels in outdoor air should not exceed 9 ppm in an eight-hour average (US EPA, 2000a). Outdoor carbon monoxide concentrations were nondetectable or ND (Table 2). Carbon monoxide levels measured in the school were also ND. *Carbon monoxide should not be present in a typical, indoor environment*. If it *is* present, indoor carbon monoxide levels should be less than or equal to outdoor levels.

Several air quality standards have been established to address airborne pollutants and prevent symptoms from exposure to these substances. The MDPH established a corrective action level concerning carbon monoxide in ice skating rinks that use fossil-fueled ice resurfacing equipment. If an operator of an indoor ice rink measures a carbon monoxide level over 30 ppm, taken 20 minutes after resurfacing within a rink, that operator must take actions to reduce carbon monoxide levels (MDPH, 1997).

ASHRAE has adopted the National Ambient-Air Quality Standards (NAAQS) as one set of criteria for assessing indoor air quality and monitoring of fresh air introduced by HVAC systems (ASHRAE, 1989). The NAAQS are standards established by the US EPA to protect the public health from 6 criteria pollutants, including carbon monoxide and particulate matter (US EPA, 2000a). As recommended by ASHRAE, pollutant levels of fresh air introduced to a building should not exceed the NAAQS (ASHRAE, 1989). The NAAQS were adopted by reference in the Building Officials & Code Administrators (BOCA) National Mechanical Code of 1993 (BOCA, 1993), which is now an HVAC standard included in the Massachusetts State Building Code (SBBRS, 1997).

As previously mentioned, the US EPA also established NAAQS for exposure to particulate matter. The NAAQS originally established exposure limits to particulate matter with a diameter of 10 μm or less (PM10). According to the NAAQS, PM10 levels should not exceed 150 microgram per cubic meter ($\mu g/m^3$) in a 24-hour average (US EPA, 2000a). These standards were adopted by both ASHRAE and BOCA. Since the issuance of the ASHRAE standard and BOCA Code, US EPA proposed a more protective standard for fine airborne particles. This more stringent, PM2.5 standard requires outdoor air particle levels be maintained below 65 $\mu g/m^3$ over a 24-hour average (US EPA, 2000a). Although both the ASHRAE standard and BOCA Code adopted the PM10 standard for evaluating air quality, BEHA uses the more protective proposed PM2.5 standard for evaluating airborne particulate matter concentrations in the indoor environment.

Outdoor PM2.5 concentrations were measured at 2 $\mu g/m^3$. Indoor levels of PM2.5 ranged from 1 to 5 $\mu g/m^3$. Frequently, indoor air levels of particulates (including PM2.5) can be at higher levels than those measured outdoors. A number of mechanical devices and/or activities that occur in schools can generate particulate during normal operations. Sources of indoor airborne particulates may include but are not limited to particles generated during the operation of fan belts in window-mounted air conditioners, cooking in the cafeteria stoves and microwave ovens; use of photocopiers, fax machines and computer printing devices; operation of an ordinary vacuum cleaner and heavy foot traffic indoors.

Indoor air quality can also be negatively influenced by the presence of materials containing volatile organic compounds (VOCs). VOCs are carbon-containing substances that have the ability to evaporate at room temperature. Frequently, exposure to low levels of total VOCs (TVOCs) may produce eye, nose, throat and/or respiratory irritation in some sensitive individuals. For example, chemicals evaporating from a paint can stored at room temperature would most likely contain VOCs. In an effort to determine whether VOCs were present in the building, air monitoring for TVOCs was conducted. An outdoor air sample was taken for comparison. Outdoor TVOC concentrations were ND.

Indoor TVOC concentrations were also ND. Please note, that the TVOC air measurements are only reflective of the indoor air concentrations present at the time of sampling. Indoor air concentrations can be greatly impacted by the use of TVOC containing products.

Several other conditions were noted during the assessment, which can affect indoor air quality. Occupants reported problems with chipmunks in modular classrooms. A chipmunk was observed entering the modular crawlspace through a hole in the exterior wall skirting (Picture 10). If chipmunks have penetrated into the building space, it is also likely that other rodents (mice) may also exist in the structure. Rodent infestation can result in indoor air quality related symptoms due to materials in their wastes. Mouse urine is known to contain a protein that is a known sensitizer (US EPA, 1992). A sensitizer is a material that can produce symptoms in exposed individuals, including running nose or skin rashes. A three-step approach is necessary to eliminate rodent infestation:

1. remove rodents;
2. clean waste products from the interior of the building; and
3. reduce/eliminate pathways/food sources that are attracting rodents.

To eliminate exposure to allergens, rodents must be removed from the building. Please note that removal, even after cleaning, may not provide immediate relief since allergens can exist in the interior for several months after rodents are eliminated (Burge, 1995). A combination of cleaning and an increase in ventilation and filtration should serve to reduce rodent associated allergens once the infestation is eliminated.

AHUs are normally equipped with filters that strain particulates from airflow. Filters used in the AHUs provide minimal filtration. In order to decrease aerosolized particulates, disposable filters with an increased dust spot efficiency can be installed. The dust spot efficiency is the ability of a filter to remove particulates of a certain diameter from air passing through the filter. Filters that have been determined by ASHRAE to meet its standard for a dust spot efficiency of a minimum of 40 percent (Minimum Efficiency Reporting Value equal to 9) would be sufficient to reduce many airborne particulates (Thornburg, 2000; MEHRC, 1997; ASHRAE, 1992). Note that increased filtration can reduce airflow produced by the AHUs by increasing resistance, a condition known as pressure drop. Prior to any increase of filtration, the HVAC systems should be evaluated by a ventilation engineer to ascertain whether they can maintain function with more efficient filters.

## Conclusions/Recommendations

In order to address the conditions described in this assessment, the following recommendations are made to improve indoor air quality.

1) Open fresh air intake vents in the rooftop AHUs.
2) Operate the ventilation system continuously during school hours.
3) Reconnect the restroom flexible duct.
4) Remove carpeting up to three feet from the threshold of exterior doors. Replace carpeting with a non-slip, nonporous material (e.g., rubber matting, tile).

5) Install flashing under the exterior door thresholds in order to prevent water penetration. Seal threshold seams with an appropriate sealant. Install a door sweep and bottom of each exterior door.

6) Reestablish drainage and remove accumulated debris from roof.

7) Remove skirting from the base of the building to examine water pooling. Seal all holes in the underside of the modular classrooms with an appropriate sealing compound to prevent air and water vapor penetration into the modular classrooms. Once sealed, replace damaged skirting materials.

8) Examine the feasibility of directing downspout water away from the base of the building.

    a) Improve the grading of the ground away from the foundation at a rate of 6 inches per every 10 feet (Lstiburek & Brennan, 2001).

    b) Install a water impermeable layer on ground surface (clay cap) to prevent water saturation of ground near foundation (Lstiburek & Brennan, 2001).

9) Use the principles of integrated pest management (IPM) to rid this building of pest. The IPM recommendations are available at the Massachusetts Department of Food and Agriculture (MDFA) website: http://www.state.ma.us/dfa/pesticides/publications/IPM_kit_for_bldg_mgrs.pdf.

10) Examine the feasibility of increasing HVAC filter efficiency. Ensure that filters are of a proper size and installed in a manner to eliminate particle bypass of the filter. Note that prior to any increase of filtration, each unit should be evaluated by a ventilation engineer as to whether they can maintain function with more efficient filters.

11) For buildings in New England, periods of low relative humidity during the winter are often unavoidable. Therefore, scrupulous cleaning practices should be adopted to minimize common indoor air contaminants whose irritant effects can be enhanced when the relative humidity is low. To control for dusts, a high efficiency particulate arrestance (HEPA) filter equipped vacuum cleaner in conjunction with wet wiping of all surfaces is recommended. Drinking water during the day can help ease some symptoms associated with a dry environment (throat and sinus irritations).

12) Consider adopting the US EPA (2000b) document, *Tools for Schools*, to maintain a good indoor air quality environment on the building. This document can be downloaded from the Internet at: http://www.epa.gov/iaq/schools/index.html.

13) Refer to resource manuals and other related indoor air quality documents for further building-wide evaluations and advice on maintaining public buildings. These materials are located on the MDPH's website: http://www.state.ma.us/dph/beha/iaq/iaqhome.htm.

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**Picture 1**

**Rooftop AHU**

**Picture 2**

**Sealed AHU Fresh Air Intake**

**Picture 3**

**Flexible Duct Disconnected from Restroom Exhaust Fan Housing**

**Picture 4**

**Accumulated Water on Roof**

**Picture 5**

**Accumulated Materials on Roof**

**Picture 6**

**Modular Building Installed Partially over Soil**

**Picture 7**

**Water Damage to Exterior Wall**

**Picture 8**

**Water Damage to Exterior Wall**

**Picture 9**

**Stairwell beneath Exterior Door Threshold**

**Picture 10**

**Chipmunk Entry Point into Crawlspace**

**Priest Street School, Modular Classroom Building** **Indoor Air Results**

**115 Priest Street, Leominster, MA** **June 11, 2004**

# Table 1

| Location/ Room | Temp (°F) | Relative Humidity (%) | Carbon Dioxide (*ppm) | Carbon Monoxide (*ppm) | TVOCs (*ppm) | PM2.5 (µg/m3) | Occupants in Room | Windows Openable | Ventilation Supply | Ventilation Exhaust | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Background (Outdoors) | 75 | 30 | 395 | ND | ND | 2 | - | - | - | - | |
| K | 74 | 35 | 717 | ND | ND | 5 | 22 | Y | Y | Y | Food storage<br>Hallway door open |
| Preschool | 72 | 39 | 597 | ND | ND | 1 | 1 | Y | Y | Y | Food storage<br>Carpet at exterior door threshold |

ppm = parts per million
µg/m3 = micrograms per cubic meter

AD = air deodorizer
AP = air purifier
aqua. = aquarium
AT = ajar ceiling tile
BD = backdraft
CD = chalk dust
CP = ceiling plaster
CT = ceiling tile
DEM = dry erase materials
design = proximity to door
FC = food container
G = gravity
GW = gypsum wallboard
M = mechanical
MT = missing ceiling tile
NC = non-carpeted
ND = non detect
PC = photocopier
PF = personal fan
plug-in = plug-in air freshener
PS = pencil shavings
sci. chem. = science chemicals
TB = tennis balls
terra. = terrarium
UF = upholstered furniture
WP = wall plaster

**Comfort Guidelines**

Carbon Dioxide: < 600 ppm = preferred
600 - 800 ppm = acceptable
> 800 ppm = indicative of ventilation problems

Temperature: 70 - 78 °F
Relative Humidity: 40 - 60%